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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

QUARTZ AND SILICA

PART II. - QUARTZ, QUARTZITE, AND SANDSTONE

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BY

R. M. SANTMYERS

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QUARTZ AND SILICA[1]

PART II. QUARTZ, QUARTZITE, AND SANDSTONE

By R. M. Santmyers[2]

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FOREWORD

Except for optical purposes and a few other special uses quartz and quartzite are to a considerable degree interchangeable. This also may be said with respect to pulverized quartz and ground silica sand, which are discussed in a separate paper of this series.

All these materials, except perhaps quartz crystals of optical grade, are abundantly available in many parts of the United States. In the form of ordinary crushed stone much of it is sold at $1 a ton or less, and ordinarily

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6473."

2 - Mineral specialist, Rare Metals and Nonmetals Division, U. S. Bureau of Mines.

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the unit value is too small to permit shipment to any considerable distance from the quarry. Optical quartz, however, may be worth $6,000 or more a ton.

OPTICAL QUARTZ

Quartz for optical use must be free of discoloration, air and gas bubbles, cracks, seams, feathers, or any other physical flaws, and be water clear. They must be single crystals and weigh at least 2 pounds, although smaller crystals can be used for cutting small lenses, wedges, beads for personal adornment, etc.

In the optical industry, one of the most important uses is for white-light saccharimeters and the plates by which these instruments are standardized.[3] Not only are these instruments used in the course of the manufacture of sugar, but it is upon their readings that the imposition of customs duties is based. In saccharimeters use generally is made of the power of the quartz to rotate the plane of polarization of plane polarized light. Sugar solutions as well as quartz have this property, the amount of rotation of the solution depending upon the concentration and the length of the solution traversed by the polarized beam. Two instruments for this work are in use today, the single wedge and the double wedge, either being satisfactory.

In this same field quartz crystals find another use in the preparation of standards for calibration of the scales used in the saccharimeter.[4] In the sugar industry these are known as quartz-control plates. They are thin disk of quartz cut in the same way that the wedges and compensation plates are cut. Each plate is made very carefully and tested and certified by the U. S. Bureau of Standards before it is put in service in the industry.

Without crystal quartz, with its peculiar rotatory power and dispersion, the present method of determining sugar concentrations would be impossible, and no other method yet invented can compete with it in speed and accuracy.

Another use of crystal quartz is for prisms and lenses in spectrographic instruments. In these instruments, however, it is not the crystallographic properties which make quartz valuable but the fact that the mineral has a very high light transmission not only in the visible region but also in the ultra-violet region of the spectrum.[5]

In the field of microscopy and especially in petrography quartz finds many uses that depend mainly upon its peculiar crystallographic properties rather than upon its wide range of transparency. In this field it is

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3 - Forrest, J. W., Crystal Quartz in Optical Industry: Foote-Prints, Foote Min. Co., Philadelphia, vol. 2, No. 2, 1929, pp. 34-35.
4 - Forrest, J. W., Work cited, pp. 35-36.
5 - Forrest, J. W., Work cited, pp. 36-37.

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also used in making the fluorescence microscope, an instrument used to study substances that exhibit the property of fluorescence.[6]

An interesting though little used application of the rotatary power of quartz is in the development of a special instrument for the measurement of color - the Ahrens chromoscope.[7]

PIEZO-ELECTRIC QUARTZ[8]

In the electrical industry clear quartz crystal of quality comparable to that used in optical instruments, in the form of thin plates, finds interesting and important uses.

The sharp resonance of a correctly cut quartz plate is the feature that has made possible the application of quartz to the radio field. Here it is used for making thin plates for controlling the frequency of radio transmitting sets and for condensors in radio-receiving apparatus. These resonators for transmitting apparatus are very compact and portable. Such resonators to oscillate in the present United States broadcast band are very small; in fact, a set of mounted resonators providing a calibrated point for each fundamental vibration and harmonics if the mounting is suitable can be carried easily in the vest pocket. The precision of these is about one-hundredth of 1 per cent. Temperature-controlled piezo-electric crystal oscillators may be used to monitor the frequency of radio stations, and automatic piezo control is used on many of the high-class radio stations in the United States so that no adjustment is necessary during operation. Under favorable conditions the frequency from a crystal-controlled radio station varies only a few thousandths of 1 per cent.

The mechanical motion of an oscillating piezo-electric quartz plate has been applied to various interesting nonradio uses. As a generator of waves in a gas it can be used to measure the propagation velocities of sound in different gases and mixtures of gases. As a generator of waves in a liquid various applications can be made, such as underwater signaling, chemical uses, etc.

For use as piezo-electric plates the following specifications are rigidly enforced:-

(a) Clear optical quality.
(b) No cracks or mechanical flaws.
(c) Either optically right or left handed, but not twinned.

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6 - Forrest, J. W., Work cited, pp. 38-39.
7 - Forrest, J. W., Work cited, p. 40.
8 - Hitchcock, R. C., Oscillating Piezo-Electric Quartz Plates: Foote-Prints, Foote Mineral Co., Philadelphia, vol. 3, 1930, pp. 3-18.

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The crystals should also show growth lines on at least two side faces to be able to determine the direction in which the optical axis lies.

Market and Prices

For optical purposes quartz crystals must be of the very highest quality. The crystals should be water clear and contain no gas or air bubbles, flaws, cracks, etc. They should contain less than 0.2 per cent impurities.

Although there is a small production in the United States of crystal quartz suitable for optical purposes, the principal sources are Brazil and Madagascar. The small output from the United States is very erratic, often being individual pieces picked up here and there by producers of other minerals, principally feldspar.

The demand in general is for crystals weighing at least 2 pounds and upward, although the prices quoted are for crystals weighing one-fourth to one-half pound apiece. The price as quoted in a trade journal[9] remained constant at $0.80 per pound in ton lots during 1929 and 1930. The crystals are quoted as being suitable for optical purposes and weigh one-fourth to one-half pound apiece. For larger crystals the price rises in proportion to size up to $3.00 or more per pound.

Purchasers

The following companies have indicated to the Bureau of Mines that they are purchasers of optical-grade crystal quartz:

Foote Mineral Co., 1608 Summer St., Philadelphia, Pa.
General Electric Co., Schenectady, N. Y.
Hanovia Chem. & Mfg. Co., Newark, N. J.
Robert A. Bautz, 236 N. Clark St., Chicago, Ill.

In a circular issued by the Naval Research Laboratory, Washington, D. C., under date of April 5, 1928, it was stated that the U. S. Navy would pay $6,000 per ton, f.o.b. San Francisco, for suitable crystals. These crystals must be single crystals weighing at least 2 pounds each. Two to 30 pounds is the size desired, although larger crystals are acceptable. Growth lines must be in evidence on at least two side faces. Information as to present prices and requirements of the Navy can probably be obtained from the Naval Research Laboratory, Bellevue, Anacostia, D. C.

FUSED-QUARTZ GLASS

Quartz glass is of two kinds, opaque (or translucent) and clear. The former is much cheaper, since any quartz of high purity, such as translucent quartz and the best quality of glass sand, can be used, and the

9 - Metal and Mineral Markets (Eng. and Min. Jour. Press quotations), New York (weekly).

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manufacturing process is much simpler than that for the clear glass. The opacity is due to inclosed microscopic bubbles of gas, either originally in the quartz or sand or occluded during melting. This type of glass is known as fused silica glass in contradistinction to the perfectly clear grade known as fused quartz glass.

The art of making clear fused quartz glass dates back to 1839, when Gaudin, in France, discovered the general thermal properties of fused quartz. Only during the past 25 or 30 years, however, has the development of clear fused quartz made rapid progress, and only during the past five years has it been produced in any great quantity. It was at the beginning of this latter period that considerable research centered around fused-quartz glass sheets and its application to combatting diseases of undernourishment, such as rickets. F. E. Lamplough first produced successfully clear fused-quartz glass sheets that would withstand weathering in England in 1925. This glass is recommended for use instead of ordinary window glass, since it has the property of allowing therapeutic rays of the sun to pass through it. Now several such types of clear fused-quartz glass are found on the American market, and its use for this purpose is growing steadily.

Fused-quartz glass in forms other than sheets is used to a great extent in a number of industries and is now replacing to a limited degree certain objects, such as lenses, wedges, etc., that were formerly cut and ground to shape from water-clear, flawless rock crystal. These articles made from clear fused quartz take the form of rods, tubes, ribbon, mercury tubes for ultra-violet ray transmission, X-ray and Roentgen tubes, glass slides for microscopic work, optical lenses, prisms, cubes, etc., and for certain chemical ware. In the motion-picture industry clear fused-quartz lenses 4⅓ inches in diameter have been employed successfully in projection machines, using currents as high as 150 amperes, and where glass lenses cracked almost daily because of the heat.

Fused quartz has a higher dielectric value than porcelain, glass, or similar materials and retains this superiority to a marked degree at high temperatures. A thickness of 1 millimeter of fused quartz provides absolute insulation against an electric current of 10,000 volts.

Method of Manufacture

For the manufacture of fused quartz glass only water-clear rock crystal, the highest quality of quartz, will readily produce a fused material without blemishes, flaws, or tint. It is much more difficult to make fused quartz of high quality from sand, even if its purity exceeds 99 per cent silica, as during the fusing process bubbles will appear due to the inclusion of air between the grains of sand. Although clear glass can be made from opaque or translucent quartz the extra cost of manufacture greatly exceeds that for the water-clear quartz generally used.

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The following description of the methods of manufacturing fused quartz is by Edward R. Berry, who writes:[10]

> There are two distinct steps in the preparation of tubes, rods, ribbon and plate; the most important of which is the initial fusion. The quartz is generally broken up and the unsuitable pieces discarded; the rest must be cleaned of all foreign matter, of which iron oxide is the most detrimental. The clear quartz crystals, which are of various sizes, are packed as densely as possible in a graphite or carbon crucible, so that during the cracking of the crystals, which is bound to occur as the temperature is raised, the parts can not separate and allow any small amount of gas which may be present to enter the many crevices and thus form bubbles. The tightly packed crucibles are packed in a modified vacuum furnace and the temperature raised as quickly as possible to the melting point. During this fusion the pressure in the furnace is kept as low as possible. The time varies but in no case over 45 minutes is necessary. The result of this first fusion is a clear transparent slug containing comparatively few bubbles ranging in size from a pin point to 2 or 3 millimeters in diameter.---This slug is now placed in another crucible which is suspended in a vertical carbon tube furnace. A graphite piston which just fits the crucible is placed on top the fused quartz slug and a weight is placed on top of a plunger attached to the piston. The slug is again brought to fusion, the bubbles are practically collapsed and by the action of the weight the quartz is extruded in the various commercial forms as required. This material is practically free from bubbles, but because of limiting dimensions it may become necessary to rework some of this, which is accomplished by the usual bench methods with an oxygen-illuminating-gas flame.
>
> When it is desired to obtain large blocks as free from bubbles as the products produced by the above method, another operation is necessary. As before, the quartz is fused in a vacuum furnace which, however, is designed to withstand very high pressures. As soon as the material is fused, the vacuum valve is closed and the pressure in the tank is brought up to some value, depending on the object in view, in less than a minute. This pressure collapses the bubbles and makes it possible to obtain very large slugs freer from bubbles than many kinds of the best optical glass.

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10 - Berry, Edward R., Clear Fused Quartz Made in the Electric Furnace: Smithsonian Rept., 1924, pp. 213-18.

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Market and Prices

Water-clear quartz crystals for use in the manufacture of ordinary clear fused quartz may contain cracks and seams; but for transparent glass of the highest quality only the purest quartz in large pieces can be used, so that the difference in the price of quartz free from bubbles and that containing comparatively few of them may appear disproportionately large. The quartz generally used is the best Brazilian pebble.[11]

The price for crystal quartz per pound, colorless, clear but flawed, in ton lots, remained constant at $.20 during 1929 and 1930.[12]

Purchasers

The following is a list of the possible purchasers of fusing quartz.

Hanovia Chem. & Mfg. Co., Newark, N. J.
Amersil Company, Inc., 88 Cypress Ave., New York, N. Y.
Robert A. Bautz, 236 N. Clark St., Chicago, Ill.
Acme-Internation X-Ray Co., 711 West Lake Street, Chicago, Ill.
Foote Mineral Co., 1609 Summer St., Philadelphia, Pa.
General Electric Co., West Lynn, Mass.
Sidio Company of America, Inc., 37-39 Murray St., New York, N. Y.

AGATE[13]

Finished agate is used for bearings of delicate balances, small mortars and pestles, burnishers and writing styles, paper knives, jewel boxes, bearings of scientific instruments, balls for water meters, and ornamental and semiprecious stone for settings and seals, brooches, beads, umbrella handles, and similar purposes.

For all mechanical uses the principal requirements are uniformity in grade and freedom from cracks, flaws, and other defects which do not allow a smooth, unbroken surface finish. For ornamental purposes, where artificial coloring is often employed, defects such as seams and variations in texture may be an advantage, as they give a varigated effect to the finished article.

The preparation of agate depends largely upon the ultimate use to be made of it. For ornamental purposes and for use as semiprecious stones agate is valued largely on account of its color and banding. Much of the agate marketed is artificially colored, which is possible because it is porous and can absorb a colored liquid. Different layers of the same specimen differ in

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11 - Spurr, J. E., and Wormser, F. E., The Marketing of Metals and Minerals: New York, 1925, p. 521.
12 - Metal and Mineral Markets (Eng. and Min. Jour.,-Press quotations) New York (weekly).
13 - Weigel, W. M., Technology and Uses of Silica and Sand: Bull. 266, Bureau of Mines, 1927.

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porosity; because of this fact a banded color can be obtained. Bauer[14] describes the methods of coloring and finishing agate at Oberstein, Germany. Details of the processes, however, are maintained as trade secrets.

FERROSILICON

Ferrosilicon, an alloy of iron and silicon, is the product of either the blast furnace or the electric furnace. In general the blast-furnace product better known as "Bessemer ferrosilicon" or "siliconeisen" has a silicon content of 7 to 15 per cent, and the electric furnace product contains over 15 per cent silicon. Occasionally even the lower silicon grades are also produced in the electric furnace.

The silicon content of ferrosilicon ranges from 7 or 8 per cent to over 90 per cent. At the lower end of the scale it grades into and overlaps silvery iron (usually 5 to 10 per cent silicon) and high-silicon pig iron (2 to 4½ per cent). Silvery irons containing up to 12 per cent of silicon are made and sold as such and are distinguished from ferrosilicon of similar silicon content only because they contain somewhat more phosphorus (over 0.1 per cent) and have a characteristic silvery fracture. Alloys of silicon and iron containing upward of 90 per cent silicon are made and sold as silicon metal.

For the manufacture of electric-furnace ferrosilicon silica in the form of vein quartz, quartzite, or sandstone may be used. Quartz and quartzite are considered superior to sandstone, as the latter tends to break down under the extreme heat needed to carry out the process. A fairly high degree of purity is desirable, although iron oxide is not objectionable, as iron in the form of ore or turnings is added to the charge. Vein quartz or quartzite averaging 97 per cent or more SiO_2 and 1 per cent or iron oxide make a satisfactory melt. It should be free from objectionable impurities, especially phosphorus and arsenic. Lime should be practically absent, under no circumstances over 0.5 per cent; and alumina should be low, under 2 per cent. The rock for this use is broken to a size from 1 inch to 6 inches, according to practice.

The quartz used for such purpose is obtainable in many localities and hence is relatively cheap, being worth generally not more than about $2 a ton delivered at the furnace. Considerable quartz is imported from Canada owing to the proximity of furnaces at Niagara Falls and to cheap water transportation.

Ferrosilicon is used in the manufacture of iron and steel both to remove dissolved oxygen and to increase the silicon content of the steel. The first function has been its principal one, but the second is growing in importance. The uses of the high and low grade varieties are similar; but in the manufacture of high-grade castings, where purity and uniformity of metal

14 - Bauer, Max, Precious Stones: London and Philadelphia, 1904, p. 522.

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are very essential, electric-furnace silicon--generally the 50 per cent product --is used. Iron foundries are large consumers of Bessemer ferrosilicon and steel foundries of the electric-furnace product. An alloy containing 75 per cent is used extensively in the production of sheet steel for laminated cores and other parts of electrical machinery. A leading use of silicon metal (97 + per cent silicon) is in aluminum die castings.

Table 1 shows the shipments of ferrosilicon (7 per cent or more silicon) from furnaces in the United States from 1919 to 1929, inclusive.

Production

Table 1.-- Shipments of Ferrosilicon from Furnaces in the United States[1]

	Gross tons	Value	Average value per ton
1919	10,445	$629,362	$60.25
1920	13,909	719,446	51.73
1921	55,099	2,548,827	46.26
1922	154,866	7,109,928	45.91
1923	184,067	9,940,772	54.00
1924	150,021	7,558,984	50.39
1925	221,387	11,405,060	51.52
1926	233,428	12,119,465	51,92
1927	232,576	11,903,782	51.18
1928	310,770	15,199,746	48.90
1929	310,280	15,730,950	50.70

1 - Davis, N. W., Iron Ore, Pig Iron and Steel: Mineral Resources of the United States, Part I., Bureau of Mines (annual).

Imports

Table 2.-- Ferrosilicon Imported for Consumption into the United States[1]

	Silicon content, gross tons	Value	Average value per ton
1919	10,445	$629,362	$60.25
1920	13,909	719,446	51.73
1921	7,858	388,420	49.43
1922	14,772	830,808	56.24
1923	11,544	1,044,221	90.45
1924	12,125	1,249,071	103.00
1925	4,556	585,193	128.44
1926	13,038	1,375,227	105.48
1927	7,347	923,158	125.65
1928	4,697	649,739	138.33
1929	9,285	1,388,423	149.53

1 - Davis, H. W., Iron Ore, Pig Iron and Steel: Mineral Resources of the United States, Part I, Bureau of Mines, (annual).

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Exports

Table 3.-- Ferrosilicon Exported from United States

	Gross tons	Value	Average value per ton
1919	1/	1/	- - -
1920	1/	1/	- - -
1921	368	$20,204	$54.90
1922	689	30,939	44.90
1923	814	31,154	38.27
1924	775	29,214	37.70
1925	1/	1/	- - -
1926	1/	1/	- - -
1927	1/	1/	- - -
1928	1/	1/	- - -
1929	1/	1/	- - -

1/ Not separately classified.

FLUXING QUARTZ

For use in fluxing quartz does not need to be of a high chemical purity, as vein quartz, quartzite, and sandstone are all used for the same purpose. A quartz carrying metal values, such as copper, gold, or silver, is more desirable, if available, than barren material. The quartz is customarily quarried by the smelting company itself, and an instance is not known where barren silica is purchased from producers directly by the smelters. For this purpose the material must be of fairly uniform size and should not break down at moderate temperatures. Line, magnesia, and iron content must be low. Siliceous fluxing material is used more often in copper smelting because such ores are more generally basic. Lead smelting plants consume relatively smaller amounts, and most iron ores already have an excess of silica. Often sufficient siliceous matter is contained in the ores to be smelted to obviate the necessity of quarrying barren quartz for the purpose.

QUARTZ FOR ACID TOWERS

While terra cotta shapes have replaced quartz to a great extent as acid-resisting packing in acid towers for the chamber process for making sulphuric acid, because they permit more efficient arrangement of surfaces and channels for counterflow of gas and liquid, at one time quartz was the only material used for this purpose.

Quartz for acid towers should look vitreous, must be free of all impurities soluble in acids (especially iron and arsenic), and should be devoid of all clay seams the acid could attack and cause the lumps to crumble. The lumps must be of uniform size, as the quartz is placed in successive layers, according to size, with the larger lumps at the bottom of the tower. The size of the lump varies according to the use to which the tower is put.

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For some purposes the lumps may range from 1 to 3 inches in diameter, while for acid scrubbing towers it is graded from about 1 inch down to pea size. Other sizes range from 2 to 8 inches, with an average of 4 inches, 12 to 18 inches, 3 to 4 inches, and a product closely sized to about 1 inch. In ammonia absorption towers the quartz is closely graded between 1¼ to 1¾ inches in diameter.

REFRACTORIES

Although some lump or vein quartz is used for refractory purposes the bulk of the material employed for silica brick and other refractories is quartzite (or "ganister"). Fine lump or crushed quartz and quartzite are also employed in the bottoms of reverberatory furnaces and as converter linings in copper and steel plants.

For copper-converter lining the quartz is crushed or ground in chaser mills to a maximum of about three-eighths to one-half inch, and any fines remain in the product. High-grade vein quartz is best, provided barren material must be employed; but siliceous material carrying even small amounts of gold, silver, or copper is used if possible, as the valuable metals enter the matte and are recovered.

For lining acid Bessemer converters about the same size material is used, but chemical purity is most important.

Siliceous linings for steel and copper furnace bottoms require quartz of rather high silica content, and sand and quartzite having a sufficiently high silica content are generally used for this purpose.

The use of pulverized quartz for refractories is limited to foundry facings and partings and, to a small extent, as an admixture to steel molding sands. The specifications generally require that approximately 65 per cent pass a 325-mesh screen, 33 per cent be retained on a 325-mesh screen, and about 20 per cent be retained on a 200-mesh screen. It should contain about 99 to 99.7 per cent SiO_2. Much of this product, however, is made from high-grade silica sand.

Silica Brick

The highly refractory nature of silica is taken advantage of in the manufacture of silica brick, now widely used in metallurgical work.[15] By far the largest part of the silica brick is manufactured from quartzites, since loose-grained rock—such as sandstones—have little value for this purpose.[16] In the United States this material is known as ganister and differs from quartzite in that it contains a natural bonding material in the form of refractory clay, sometimes as much as 10 per cent.

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15 - Spurr, J. E., and Wormser, F. E., The Marketing of Metals and Minerals: New York, 1925, p. 518.

16 - Cole, L. H., Silica in Canada; Part I: Canadian Dept. of Mines, Mines Branch, No. 555, 1923, p. 21.

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The specifications for ganister are that it should contain about 98 per cent silica and not more than 1½ per cent alumina and that the material should be of such nature as to be crushed into fine angular fragments. It is generally crushed to pass an 8-mesh screen.

When silica brick is made from quartzite the bond generally used is lime, about 2 per cent being added to the crushed rock in the form of milk of lime. The quartzite and lime are milled thoroughly in wet pans until a slightly cohesive mass is produced. The wet mass is molded by hand, then dried, and afterward repressed by machinery. When thoroughly dried, the pressed bricks are set in kilns to a finishing temperature of 1500° C. Upon firing the bricks should expand and swell without perceptible cracking. For this reason silica bricks are chiefly used where great heat resistance combined with an absence of shrinkage is essential, such as in arches, crowns, and higher parts of furnaces and kilns, for the upper part of glass furnaces, and for all parts above the floor level in by-product coke ovens.

FILLERS

Considerable quantities of crushed and pulverized quartz are used as fillers. When quartz is used alone it is virtually limited to what is known as "paste-wood filler." The sharp, angular quartz grains block up or bridge over the larger pores in the grain of the wood but do not prevent capillary action of the liquid into the smaller pores. Soft silicas, including tripoli, are used more widely in paints and fillers. Quartz, however, is superior to tripoli strictly as a wood filler.[17] As fillers in wood paste and paint, the general requirements of quartz are chemical purity or freedom from substances which will react with the vehicle, sharpness or angularity, lack of color or tint, and fineness.

Only a small amount of pulverized crystalline quartz is used in rubber compounds, as it is difficult to grind it to the desired fineness. The edges of the individual particles of pulverized quartz are very sharp and would tend to cut the rubber when stretched, and the glassy surface does not give good adhesion between the rubber and the mineral. What little is used is added to hard-rubber articles for acid-resisting purposes, such as battery jars and chemical apparatus. A small amount of pulverized quartz is used as a filler in rubber erasers, for its abrasive properties.

Fairly large quantities of quartz are used in gypsum-plaster preparations, especially wallboard. The properties that make it desirable for this purpose are its refractoriness, whiteness, and chemical inertness; moreover, it is cheap and reduces expansion on setting. Most of the material so used, however, is ground from quartz sand rather than vein quartz.

In the manufacture of magnesium oxychloride cement and plaster various aggregates are used in the mix, which usually consists of sand, finely

17 - Weigel, W. M., Work cited, p. 31.

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ground silica, and some other material, such as wood flour and a coloring pigment. Any silica will serve the purpose if it is white enough, and a sand of the grade of good glass sand is satisfactory. Some pulverized quartz is used, but when good white sand is available it is preferred because of its lower cost.

Many of the uses of diatomite and tripoli are in the nature of fillers, and these will be discussed under the respective headings.

CERAMICS

One of the largest and most important uses of quartz is in the manufacture of whiteware and enamel.[18] In the pottery trade it is generally called "flint," as true flint was the material originally used.

Quartz is used in the body of whiteware to reduce the drying and firing shrinkage and give the body a certain rigidity to combat deformation; moreover, it makes the body more porous, promotes quicker drying and permits the escape of steam and other gases.

Quartz is also used in mixtures for enameling iron and steel as a source of silica to combine with or flux the basic oxides. Although flint, chalcedony, and tripoli are used in whiteware and enamel in the United States by far the larger part of the silica so used is in the form of vein quartz and pulverized sand.

The chemical requirements are the same for whiteware and enamel. Iron and other metallic oxides are extremely objectionable, although small amounts are always present. Small quantities of alumina are also generally present; as large amounts of alumina from the clay and feldspar used are always in the finished product, its presence in the quartz should not be objectionable, but potters prefer a nearly pure product to assure a uniform mixture and allow calculation of quartz as 100 per cent in their formulas.

Crushed quartz is sometimes used as placing sand in the burning of ceramic ware, especially when a coarser product than sand is desired. Vein quartz is superior to fine gravel, as it is obtained in pure form and has sharp points of contact.

ABRASIVE INDUSTRY

Quartz abrasives are used to a considerable extent in industry, although in common with other natural abrasives they have suffered in recent years from the competition of artificial abrasives. Segmental pulpstones, which are constructed of artificial abrasives and attached to a core of concrete or metal, are finding increasing use as substitutes for natural pulpstones. Likewise the output of burrstones and millstones is showing a decrease,

18 - Weigel, W. M., Work cited, pp. 33-34.

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as they are being replaced by hammer mills and by tube and ball mills. This, however, does not hold true for pulverizing minerals and substances where contamination by iron must be avoided. Crushed quartz is used in sandpaper, and quartz sand and sandstone are employed in buffing compounds, metal polishes, grinding pebbles, grindstones, pulpstones, and whetstones, for sand blasting, for wire-saw cutting of slate, marble, and stone, and for cutting and grinding of glass, etc. Probably the largest single use as an abrasive is for polishing plate glass.

Sandpaper

The abrasive base for sandpaper is not sand but crushed and graded quartz. Quartz grains obtained by crushing vein or massive quartz were formerly widely employed as abrasives, especially as sandpaper coating; emery was the chief competitor in that field. The rapid development of the artificial abrasives silicon carbide and fused aluminum oxide with their superior hardness, sharpness, and tougher grain and improvements in methods of recovery and preparation of garnet have caused these substances largely to displace quartz as an abrasive, although its effect has been felt less in the sandpaper industry than in other abrasive industries.

For the coating of sandpaper crushed quartz is much better than either sand or quartzite, as the former lacks the sharp cutting edges and the latter is expensive to prepare.

True flint paper is made from the flint pebbles found in the chalk deposits of the southeast coast of England and in France. The flint is crushed and ground and is superior to quartz for abrasive cloths and paper.

Abrasive and Buffing Compounds

Pulverized quartz is used as an abrasive in soaps and in scouring and buffing compounds. Some of the pulverized material is air-floated and used in metal polishes. This material all passes a 325-mesh screen and although extremely fine the angularity of the grains is still evident. Neither sand nor crushed quartzite is used for this purpose.

Tube-Mill Lining

Siliceous linings are used for all types of mills that grind materials that must be kept free from contamination by iron. Such mills include those where all ceramic materials, most paint pigments, and the best grades of whiting, barite and enamels are ground. Siliceous linings are still used to some extent in ore-dressing and metallurgical plants and quite extensively by the cement industry.

Most of the siliceous linings used in these mills in the United States is flint imported from Belgium. The United States, however, is able

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to compete to some extent with Belgium, its output being primarily in the form of quartzite from Jasper, Minn., and flint from Iron City and St. Joseph, Tenn.[19]

The quartzite from Jasper, Minn., is quarried in large blocks and is split into slabs parallel to the bedding and as thick as one of the smaller dimensions of the lining block. The wearing face of the finished block is always made parallel to the natural bed of the stone. All standard liners are cut 5 inches wide and 8 to 12 inches long, depending on specifications, and 3, 4, or 5 inches thick according to use.

In the Tennessee district the flint occurs in thin layers, which makes fabrication of the lining blocks easier than if the material were massive. They are trimmed to a uniform thickness of about 5 inches; the length ranges from 6 to 14 inches and the width from 5 to 8 inches.

At both places practically all the finishing is done by hand with chisel and hammer while the splitting is done with plugs and feathers.

Grinding Pebbles

Extremely hard and tough rounded pebbles, usually of flint, are used in cylindrical or conical mills for grinding ores and minerals. Steel balls have now largely replaced pebbles, but when contamination of the product by iron must be prevented pebbles are the grinding medium generally used.

Domestic production of grinding pebbles is from California. The pebbles are gathered or dug from beach deposits and sorted and graded by hand, and all faulty and defective stones are discarded. The selected pebbles are again sorted into approximately uniform sizes 2, 3, 4, and 5 inches in diameter.

Most of the foreign flint pebbles are obtained from deposits in Greenland and Belgium and from the sea coast of France between Havre and St. Valery-sur-Somme. The Greenland stones are sent to Denmark, are known as Danish pebbles, and on account of their great hardness and toughness are recognized as the standard.

The imperfect stones from these foreign sources are laid aside in the sorting and are later crushed and ground into what is known as "potters' flint."

Another product called pebbles but in reality rounded cubes has been used to some extent and is produced at Jasper, Minn. Quartzite lining blocks

19 - Weigel, W. M., Domestic Tube-Mill Lining Successfully Meets Foreign Competition: Eng. and Min. Jour.-Press, vol. 118, Dec. 13, 1924, p. 925.

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culled because they are off size, stone unsuitable for liners on account of size or unsoundness, and original quarry blocks are worked up into cubes the same as the liners. The cubes are cut 2½ to 6 inches. For grinding silica, feldspar, and glaze the corners are rounded off, reducing the weight about 23 per cent - quite a saving if freight charges to consumers are high. Concentrating and cement plants use the square-cornered rough cubes.

Grindstones, Pulpstones, Burrstones, Millstones, and Whetstones

For the manufacture of these and similar products abrasive sandstones are used. The grade of the material used in each instance differs somewhat.

A sandstone suitable for grindstones must be of uniform hardness, have a sharp and even grain, and be free of clay and other impurities.[20] The hardness is important, for if the stone is too soft it wears away rapidly, causing coarse and uneven grinding; if it is too hard it glazes and cuts so slowly as to be useless. A good grindstone must have just enough cementing material to hold the grains firmly. The cements are usually limonite, clay, calcite, and quartz. These may occur individually as the sole constituent or be mixed in varying proportions, forming argillaceous matter. The size of the stones produced ranges from less than 1 foot in diameter (with a weight of less than 1 pound) to 6 or 7 feet in diameter by 16 inches in thickness. The larger stones must be especially free from all unsoundness, for even the comparatively low speeds at which they are operated set up centrifugal stresse In general, the fine-grained stone is made into the smaller-size stone and the coarse-grained into the larger stones.

Pulpstones are large revolving stones used to grind wood pulp for paper manufacture. The sandstone used for this purpose is somewhat similar in texture to that used for grindstones, and in some places the same quarry furnishes both types of stone, but invariably from different beds. The sandstone bed must be at least 3 feet thick to make even the smallest pulpstones.[21] Good strength and freedom from unsoundness are essential, as heavy stresses are set up not only by the comparatively high speeds but by the pressure of the wood being ground. The stones revolve from 200 to 225 r.p.m., with a feed pressure of 60 to 125 pounds per square inch.

A good pulpstone should cut fast, produce fibers neither too coarse nor too fine, be medium hard, possess a long life, wear evenly, and withstand the strain. To produce the long thin fibers the stone should tear and not cut, hence sandstones comprised of subangular grains are desirable.

The usual size of a pulpstone is a face of 26 or 27 inches and a diameter of 54 inches, but a variety of sizes up to the magazine grinders of 54 by 62 inches is used.[22]

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20 - Eardley-Wilmot, V. L., Abrasives; Part I, Siliceous Abrasives: Mines Branch, Canadian Dept. of Mines, No. 673, 1927, pp. 2-3.
21 - Eardley-Wilmot, V. L., Work cited, p. 35.
22 - Eardley-Wilmot, V. L., Work cited, p. 35.

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The true burrstone is a white to gray or slightly yellowish form of chalcedonic silica. The stone has a coarse cellular structure, the holes frequently being due to the dissolving out of calcareous fossils. It has about the same hardness as flint but is not so brittle and possesses a straight fracture. Its sharp cutting power is due to the toughness of the rock and its numerous pores and cavities. It was originally used as horizontal, circular "millstones" for grinding grain but is now also used for a variety of other purposes, such as in grinding paint, cement, gypsum, fertilizers, etc., and in the preparation of graphite or other minerals. Its use, however, is declining, as it is being replaced by artificial wheels, hammer mills, tube mills, etc.

The term millstone, which now includes the true burrstone, is applied somewhat loosely to include circular stones revolved on a horizontal plane as well as those run on edge. They may be made from any hard and suitable rock, ranging from a sandstone, basalt, or granite to a quartz conglomerate.[23]

The stones are used for similar purposes and range in diameter from 18 inches to 6 feet and in face from 1 to 2 feet. Like burrstones, it is being replaced by artificial stones and more modern types of grinding equipment.

Whetstones are generally small stones to be used by hand for sharpening tools. Sandstones and fine-mica schists are used for the coarser stones, while siliceous clay rocks and particularly the fine compact stones made of quartz mud, such as the Arkansas stone or novaculite, form the more desirable varieties of whetstones such as hones and oilstones. These stones are made into a number of different shapes, but the rectangular "bench" stones and wedge-shaped "round-edge slips," however, continue to be popular for hand and mechanical tool sharpening. Sometimes a very fine-grained and a medium-grained stone are cemented together, the coarser side for fast cutting and the finer side for finish sharpening.

Producers

The companies producing grindstones and pulpstones in the United States in 1929, with the locations of the deposits from which the stone was obtained, were as follows:[24]

Michigan

Huron County: Grind Stone City--The Cleveland Quarries Co. (successor to The Cleveland Stone Co.) (address, Cleveland, Ohio); grindstones.

Ohio

Cuyahoga County: Berea--The Cleveland Quarries Co. (successor to The Cleveland Stone Co., address, Cleveland); grindstones, lathe stones.

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23 - Eardley-Wilmot, V. L., Work cited, p. 47.
24 - Bowles, Oliver, Abrasive Materials: Mineral Resources of United States Bureau of Mines, 1929, Part II, pp. 65-81.

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Holmes County:
Glenmont--The Briar Hill Stone Co.; grindstones.
Killbuck--Mount Pisbia Stone Co. (address, Elgin); grindstones.
Jefferson County:
Empire--Smallwood Stone Co. (address, Steubenville); pulpstones.
Hammondsville--The International Pulpstone Co. (address, Elyria); pulpstones.
Lorain County:
Amherst--The Cleveland Quarries Co. (successor to The Cleveland Stone Co. and The Ohio Quarries Co.; address, Cleveland); grindstones.
Columbia Station--Columbia Stone Co.; grindstones.
Kipton--The Nicholl Stone Co. (address, Lorain); grindstones.
Washington County:
Constitution--The Constitution Stone Co.; grindstones.
Marietta--
The Cleveland Quarries Co. (successor to The Cleveland Stone Co.; address, Cleveland); grindstones.
The Eureka Stone Co.; grindstones.
The Hall Grindstone Co.; grindstones.
Ohio Valley Stone Co.; grindstones.

Washington

Pierce County: Wilkeson--Walker Cut Stone Co. (address, Tacoma); pulpstones.

West Virginia

Boone County: Jeffery--The International Pulpstone Co. (address, Elyria, Ohio); pulpstones.
Jackson County: Sherman--The Eureka Stone Co. (address, Marietta, Ohio); grindstones.
Monongalia County:
Fairmont (near)--The Smallwood-Low Stone Co. (address, Fairmont); pulpstones.
Little Falls--The West Virginia Pulpstone Corporation (address, Cleveland, Ohio); pulpstones.
Opekiska--
The General Stone Co. (address, Amherst, Ohio); pulpstones.
Smallwood Stone Co. (address, Steubenville, Ohio); pulpstones.
Uffington--Uffington Stone Co.; pulpstones.
Pleasants County: St. Marys--Ohio Valley Stone Co. (address, Marietta, Ohio); grindstones.
Wetzel County: Littleton--American Stone Co.; grindstones and pulpstones.

The manufacture of oilstones and other whetstones, scythestones, and rubbing stones from natural stone in 1929 and the sources of their raw materials were as follows:[25]

25 - Bowles, Oliver, Abrasive Materials: Mineral Resources of the United States Bureau of Mines, 1929, Part II, pp. 65-81.

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The American Rubbing Stone Co., Cincinnati, Ohio: Whetstones and rubbing stones; manufactured from sandstone quarried at Floyds Knobs, Floyd County, Ind.

The Bracher Co., Belleville, N. J.: Oilstones; manufactured from novaculite obtained from quarries near Hot Springs, Garland County, Ark.

J. A. Chaillaux, West Baden, Ind.: Scythestones; manufactured from sandstone quarried at McDermott, Scioto County, Ohio. Stone also sold to other companies for the manufacture of whetstones.

The Cleveland Quarries Co. (successor to The Cleveland Stone Co.), Cleveland, Ohio: Scythestones, lathe stones, and holystones; manufactured from stone obtained at Berea, Cuyahoga County, and Amherst, Lorain County, Ohio.

Garland Whetstone & Realty Co., Hot Springs, Ark.: Produces rough stone, in Garland County, for oilstones, some of which is shipped abroad and some sold to manufacturers in this country.

Pike Manufacturing Co., Pike, N. H.:

Oilstones; manufactured from novaculite obtained from quarries near Hot Springs, Garland County, Ark.

Whetstones; manufactured from sandstone obtained from quarries near West Baden, Orange County, Ind., and McDermott, Scioto County, Ohio.

Scythestones; manufactured from schist quarried at Barton, Orleans County, Vt.

Western Quarry Co., Tenino, Washington: Holystones; manufactured from sandstone quarried at Tenino, Thurston County, Wash.

DIMENSION STONE

Sandstone is used widely for both exterior and interior building.[26] Its homogenity of composition and resistance to the solvent action of rain water make it especially useful for exterior work. It may be sawed or cut for building blocks either as even-course stone or broken ashlar and be used for steps, caps, sills, water tables, coping, etc. For interior uses the more attractive types are in demand, those that have a color banding being employed to a great extent. Many sandstones are well adapted for carving, and attractive designs carved from sandstone are to be seen in many buildings.

Heavy blocks of sandstone were once used extensively in bridges and are yet used considerably for this purpose.

As quartz, the chief constituent of sandstone, is the most resistant to weathering of all common minerals, a well-cemented sandstone is among the most durable of all building stones.

Color, uniformity of texture, size of grain, impurities, crushing strength, porosity, and size of blocks available in a deposit are all

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26 - Bowles, Oliver, Sandstone Quarrying in the United States: Bull. 124, Bureau of Mines, 1917, p. 19.

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important when a sandstone is to be considered for building construction purposes.

Although uniformity in the distribution of color is to be desired for most structural purposes rocks having streaks or bands of color may in some places give very attractive effects for interior decoration and are now used extensively for this purpose where before they were discarded as waste.

Uniformity of texture (grain size) is desirable in the better grades of commercial sandstones. For exterior use in building construction this is important as otherwise it would give an uneven appearance over the wall surface.

Crushing strength of sandstones differs widely in different deposits. Sandstones that are in other respects suitable for building are usually strong enough for all ordinary uses, owing to the fact that a poorly cemented rock is generally condemned on account of friability before it is condemned on account of low crushing strength.

The porosity or percentage of pore space in sandstones is in general greater than in most other rocks, an important factor when the stone is to be considered for structural purposes, as a sandstone having high porosity has also a high ratio of absorption, a property to be carefully avoided when the stone is to be used for this purpose.

Whether or not a sandstone deposit is suitable for the production of building block depends to a great extent upon the size of blocks that can be quarried. In some deposits there are open planes of separation at intervals of several inches or several feet. Only those having the open planes a considerable distance apart are suitable for quarrying building blocks. Other structural fractures to be taken into consideration are cross bedding, joints, cutters, and reeds.

Quartzite is used to some extent as a building stone in localities where difficulty of working is balanced by high freight rates on stone from distant quarries. Although quartzite is hard and durable it occurs more often in fairly thin beds which do not permit blocks of the required size to be quarried. Furthermore, it is more difficult to fabricate than sandstone, which it resembles, and lacks the ornamental value of granite, although it is harder.

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